REPORT ON THE PRESENT STATE OF CELESTIAL PHOTOGRAPHY IN ENGLAND.

In bringing before the Association the present Report it will be only necessary, after referring briefly to the labours of others, to confine myself to an account of my personal experience; for, although other observers have occasionally made experiments in Celestial Photography, there has not been any systematic pursuit of this branch of Astronomy in England, except in my Observatory, and under my immediate superintendence in the Kew Observatory.

Part 1.—*Historical Outline.*

The late Professor Bond of Cambridge, in conjunction with Messrs. Whipple and Black of Boston in the United States, was the first to make a photographic picture of any celestial body. By placing a daguerreotype plate in the focus of the great refractor of the Harvard Observatory, of 15 inches aperture, he obtained a daguerreotype of our satellite. This was, I believe, about the year 1850, for I remember seeing one of these pictures in the Exhibition of 1851, and some were exhibited at the meeting of the Royal Astronomical Society in May 1851. The experiments were discontinued after a time in consequence of irregularities in the going of the clock-work driver, and were not resumed again till 1857, when new clock machinery was attached to the telescope*.

At the latter end of 1852, I made some successful positive lunar photographs in from ten to thirty seconds on a collodion film, by means of an equatorially mounted reflecting telescope of 13 inches aperture, and 10 feet focal length, made in my workshop, the optical portion with my own hands; and I believe I was the first to use the then recently discovered collodion in celestial photography†. In taking these early photographs, I was assisted by my friend Mr. Thornthwaite, who was familiar with the employment of that new medium‡. At that period, I had not applied any mechanical driving motion to the telescope, so that I was constrained to contrive some other means of following the moon's apparent motion; this was accomplished by hand; in the first instance, by keeping a lunar crater always on the wire of the finder by means of the ordinary hand-gear of the telescope, but afterwards by means of a sliding frame fixed in the eye-piece holder, the motion of the slide being adjustable to suit the apparent motion of our satellite; the pictorial image of the moon could be seen through the collodion film, and could be rendered immoveable in relation to the collodion plate, by causing one of the craters to remain always in apparent contact with a broad wire placed in the focus of a compound microscope, affixed at the back of the little camera box, which held the plate. Although these photographs were taken under the disadvantage referred to, namely, the want of an automatic driving motion, excellent results were nevertheless obtained, which proved how perfectly the hand may be made to obey the eye. I could not take photographs of the moon in this way alone, but required always the aid of an experienced coadjutor, willing to lose the greater portion of a night's rest, often to be disappointed by failures resulting from the state of the weather, and numberless impediments sufficient to damp the ardour of the most enthusiastic. For some months Mr. Thornthwaite was so kind as to continue his valuable aid, and several good positive pictures were obtained; but the difficulties we had to encounter were so great that it was at last resolved to discontinue the experiments until such time as a driving motion could be

* Astronomische Nachrichten, No. 1105, p. 1.

† These pictures were exhibited in the early part of 1853 at the Royal Astron. Society.

‡ Mr. Archer applied the solution of gun cotton (collodion) to photography in 1851, and suggested pyrogallic acid for developing the latent image.

§ Monthly Notices of the Roy. Ast. Soc. vol. xviii. p. 16.

applied to the telescope. This was done early in 1857 §, since which period I have unremittingly followed up the subject of celestial photography whenever my occupations and the state of the atmosphere have permitted me to do so. With what result, the Association will have an opportunity of judging by the examples exhibited*.

Professor Phillips, aided by Mr. Bates, obtained some lunar photographs in July 1853, and communicated the results of his experience in a valuable paper at the Hull meeting of the Association†. Mr Hartnup of Liverpool, aided by Mr. J. A. Forrest, Mr. McInnes, Mr. Crooke, and other photographers, took some good pictures of the moon in 1854‡; Father Secchi, at Rome, and more recently Mr. Fry, in Mr. Howell's observatory at Brighton, and Mr. Huggins, near London, have also produced lunar pictures: these experiments were in all cases made with refracting telescopes, corrected for the visual ray. Professor Bond, in April 1857, applied the process with promise of a fruitful future, in measuring the distance and angle of position of double stars§, and also in the determination of their magnitudes; just previous to his decease, this new application of the art appears to have engaged his attention more than lunar photography. He succeeded in obtaining pictures of fixed stars down to the 6–7th magnitude.

The Photographic Picture compared with the Optical Image.

It will render what I shall hereafter have to say more easily understood if I commence by bringing under notice what happens in applying photography to sidereal astronomy. The optical image of a fixed star, it will be remembered, is not a mathematical but an optical point, which, in consequence of the properties of light, is seen with the telescope as a very minute disc, surrounded by rings, which become fainter and wider apart as they enlarge, these rings being always more or less broken up, according to the state of the atmosphere. The photographic image must, therefore, be of a certain size, but it is after all a mere speck, difficult to find among other specks which are seen in the most perfect collodion film, when it is viewed with a magnifying power.

For example, let it be supposed that a telescope of sufficient aperture is turned upon α Lyræ; a star conveniently situated from its great meridional altitude for photography, and moreover sufficiently brilliant to give a nearly instantaneous picture: if the telescope be steadily supported at rest, the star will, in consequence of the earth's rotation, course along the field of the telescope, in a line parallel to the earth's equator, and, as it produces an instantaneous picture, the image obtained is a streak, representing the path of the star. We might be led to expect, *a priori*, that this line, for a short distance, would appear straight; but, so far from this being the case, it is broken up and distorted, and consists of a great number of undulating points, crowded in some places, and scattered in others. This distortion arises from the disturbances in our atmosphere which cause the star to flicker.

* The photographs exhibited at the Aberdeen Meeting were the following:—Two original negatives which would bear considerable magnifying power; two positive enlarged copies of other negatives, eight inches in diameter, which would bear still further enlargement with a lens of low power; twelve enlarged positives of the Moon in different phases, $3\frac{1}{2}$ inches in diameter, among which were three, showing the progress of the lunar eclipse on February 27, 1858; enlarged positive copies of Jupiter, exhibiting his belts and satellites; lastly, a photograph of Saturn and the Moon taken together at the recent occultation of that planet just after the planet had emerged from the moon's bright limb (May 8, 1859). The last-named photograph was produced in 15 seconds;—a remarkably rapid result for so faint an object as Saturn. The planet on this occasion was seen to be of about the same brilliancy as the Mare Crisium situated near the moon's western limb, with which the planet could be readily compared, from its proximity to that lunar district.

† Report of Brit. Assoc. 1853, Trans. Sect. A, p. 14. ‡ Ibid. Sect. B, p. 66.

§ Astronomische Nachrichten, No. 1105.

In the foregoing remarks, the telescope was supposed to be at rest; now let it be assumed that the telescope is mounted on an axis parallel with the earth's axis, and provided with a driving apparatus, capable of carrying the telescope round in the direction of the star's apparent path so equably, that, if viewed with a micrometer eye-piece, the image of the star would remain always in contact with one of the wires of the eye-piece. The photographic picture of a star, obtained by a telescope under these conditions after some seconds' exposure, is not one single clear disc or point, but a conglomeration of points, extending over a greater or less area, according as the atmosphere has during the interval produced more or less flickering.

If a mere speck, like a fixed star, acquires comparatively large dimensions on a sensitized plate in consequence of atmospheric disturbances, every optical point in an image of other celestial objects must, from the same cause, occupy a space of greater dimensions than it would if no disturbing influences existed. When the telescope is employed optically, the mind can make out the proper figure of the object, although its image dances before the eye several times in a second, and is able to select for remembrance only the states of most perfect definition; on the other hand, a photographic plate registers all the disturbances. The photographic picture will consequently never be so perfect as the optical image with the same telescope, until we can produce photographs of celestial objects instantaneously: we are still a long way from this desirable end.

Relative Advantages of Reflecting and Refracting Telescopes for Photography.

With refracting telescopes, the photographic focus of a point of light occupies a larger area than with reflectors; this is especially the case with Astronomical Telescopes, because they are corrected so as to produce the best optical image, and the outstanding chemical rays are dispersed around the luminous focus*. The reflecting telescope has, therefore, considerable advantage over the refracting telescope for celestial photography, on account of all rays coming to focus in the same plane; hence, the focus having been adjusted for the luminous image, it is correct for the chemical image, and has not to be disturbed, as with a refractor. In the telescope employed by Professor Phillips, of 6¼ inches aperture and 11 feet focal length, the actinic focus was found to be 0·75 inch beyond the visual focus; and in the Liverpool Equatorial of 12½ feet focal length the actinic focus was 0·8 inch beyond the visual focus. With my telescope the focusing is critically effected with the aid of a magnifier, the image being received on a piece of ground glass placed temporarily in the actual slide destined to contain the sensitized plate; a second piece of ground glass fixed in a frame is put into the camera just previous to each operation, for the purpose of placing the telescope in position; but the focusing is always effected in the manner described, for the goodness of the picture depends greatly on the accuracy of this adjustment. I attribute much of my success to the employment of a reflector, while my fellow-labourers in the same field have used refractors.

Actual Process employed at the Cranford Observatory.

With the view of facilitating the labours of others desirous of entering the field of photography, I will now describe, with all necessary minuteness, the process finally adopted after many trials and failures; I would remark at the same time that it is quite impossible to give such directions as will enable another operator to ensure perfect results, as this can only be attained by perseverance, long practice, and a strong determination to overcome obstacle after obstacle as it arises,—therefore, no one need hope for

* Refracting telescopes can be specially corrected for the chemical focus in the same way as Camera lenses.

even moderate success if he dabbles in celestial photography in a desultory manner, as with an amusement to be taken up and laid aside.

In order to prosecute celestial photography successfully, there must be, in close contiguity with the telescope, a Photographic Room, abundantly supplied with both common and rain water. The water-taps should project over a sink, so as to reach about a foot from the wall. The rain water is conveniently kept in and filtered by an ordinary stone-ware filter. The photographic room may be lighted generally by means of an ordinary Argand reading lamp, over the shade of which hangs a lantern-like curtain made of two thicknesses of deep-yellow calico; but the plate, during the development of the picture, must be illuminated locally by a night-light before which a yellow screen is placed. The photographic room should be furnished with a stove, burning wood or charcoal, which will keep alight for a long time, in order that its temperature may never fall much below 50° F. during the winter.

In my earlier experiments, the positive process was invariably employed on account of its greater rapidity; but so many details, visible by transmitted light in a positive, are lost when it is afterwards viewed by reflected light, that endeavours were made to render the negative process equally rapid. After many trials, I succeeded in this; and I now never have recourse to the positive process, except for some special object.

Glass used.—It is of course necessary to have the plate somewhat larger than the object to be taken; the size used when the telescope is employed as a Newtonian is $2\frac{5}{8}$ inches by $3\frac{1}{8}$ inches. When the pictures are taken by the direct method, the plates are circular, and $2\frac{3}{4}$ inches in diameter. The outside diameter of the slide to contain the circular plate is $3\frac{1}{4}$ inches, the exact size of the cell of the diagonal mirror, so that no more light is stopped out by the plate-holder than by the small mirror.

The glass used is the "extra white patent plate," and I have it selected as free from specks and bubbles as possible, but nevertheless I have frequently to reject about one-third of those discs which are supplied to me.

Mode of Cleaning the Plate.—The glass is cleaned in the ordinary way by means of tripoli powder, mixed up with three parts of spirit of wine and one of liquid ammonia, to the consistence of cream. For drying the plates I am provided with *two** cloths, which, in the first instance, have been carefully washed with soda (avoiding the use of soap), and repeatedly rinsed in water. Each time after being used, these cloths are thoroughly dried, but they need not be washed for months together. For the final wiping of the plate a piece of wash-leather is employed, also carefully dried before being used.

A piece of grit-stone, such as is used by mowers to sharpen scythes, must be at hand, for the purpose of grinding the edges of the glass plate and making scratches on the margin of the two surfaces, in order to cause the more perfect adherence of the collodion,

The plate to be cleaned is placed on a sheet of cartridge paper, and rubbed thoroughly, first on one side, then on the other, with a piece of *new* cotton-wool moistened with the tripoli mixture, above described. It is then washed in a stream of water, the fingers being used, if necessary, to aid in removing the adhering tripoli. Holding the plate while still wet, and without touching the surface, one edge after the other is rubbed on the grit-stone; the glass imbeds itself in the friable stone, and thus the borders of the two surfaces get scratched, and the edge is ground at the same time. After the four edges have been so ground, or, if the plate be circular, the whole periphery has been rubbed, the hands and plate are well washed, to remove all grit, and the plate placed edgewise for a few seconds on a marble slab. With dry

* It is disadvantageous to employ more cloths than are absolutely necessary.

hands, I take up the plate by the edge, being now very careful not to touch the surface with the hand, and wipe it, first with one cloth, then thoroughly dry with the second, and lastly, rub both surfaces at the same time with the dry wash-leather. I afterwards breathe on each side of the plate, to ascertain whether it is clean, wipe off the condensed moisture and place the plate in a grooved box, with the best surface turned to face a marked end of the box, so as to know on which side to pour the collodion. Proceeding in the above-described manner, I have never any failure attributable to a dirty plate, and can feel certain of obtaining four or five good pictures of the moon out of about seven plates generally used. I am usually, however, provided with one or two dozen cleaned plates, for it is desirable to have a sufficient reserve, and experience has proved that plates so cleaned may be used even after a week, if the box containing them be kept in a dry room.

The Bath.—It is of the utmost importance that the nitrate of silver bath should be in the most sensitive condition; the rapidity of the process appears to depend in a great measure on its not being in the slightest degree acid, but as nearly neutral as possible. It is almost needless to add that, for such a refined application of photography as that under consideration, the solution should be kept in glass in preference to gutta percha. The vessel must be carefully covered, to exclude dust, and, from time to time, the solution should be filtered through pure filtering paper (Swedish paper). The nitrate of silver used in the preparation of the bath is invariably fused in my own laboratory, in quantities never exceeding a drachm at one time, the requisite heat being gradually applied, and care being taken not to raise the temperature higher than is necessary to effect the fusion.

The solution I employ is the ordinary one of thirty grains of nitrate of silver to the ounce of water, with a quarter of a grain of iodide of potassium. In the preparation of a bath, after the mixing of the nitrate of silver, dissolved in a small portion of the water, with the solution of iodide of potassium, it is customary to add the remaining chief bulk of water, which causes an immediate precipitation of iodide of silver, and then to filter the liquid after the lapse of half an hour. It is, however, advisable to agitate the solution from time to time, during several hours before it is filtered; for unless this be done, the bath does not become thoroughly saturated with iodide of silver, and has a tendency for some time to dissolve a portion of the iodide of silver which first forms in collodion immersed in it.

I avoid adding alcohol or acetic acid to the bath, for these substances impair its sensitiveness. As, after use for a certain time, the bath becomes charged with more or less alcohol and ether, and their products of oxidation, its properties become changed, and a picture cannot be taken with it with sufficient rapidity; when I find this to occur, I discard the bath and make a fresh one. The bath, in its most sensitive state, usually exhibits a very feeble alkaline reaction with reddened litmus paper, and if it be found to have a tendency to fog, it is corrected in this way:—A single drop of pure nitric acid is taken on the point of a glass rod, and mixed with a drachm of distilled water; with this diluted acid (1 to 60) I moisten the point of the glass rod and stir it about well in the bath, which contains about fourteen fluid ounces of solution, and make a trial. If it still fogs, the acidification is repeated; and thus, after several trials, the fault is corrected. It is better to proceed in this manner than to rely on litmus papers as a test for neutrality; the object being to retain the bath in as sensitive a state as possible, the test by light is the only one to be ultimately depended on.

Moist hydrated oxide of silver may be used to bring back a bath, which has become acid by use, to a neutral state, and by the subsequent careful

addition of dilute nitric acid it may be made to work; but all additions of acetate of soda, carbonate of soda, or acetic acid, are quite inefficacious for correcting a bath that does not work satisfactorily. In order to obtain the extreme point of sensitiveness, the best plan on the whole is to make a new bath; the silver being, as is well known, easily recoverable from its solutions and in part, by evaporation and crystallization, as nitrate.

Collodion.—The condition of the collodion is also an all-important point, and it appears to be very capricious in its properties. It is preferable not to make the collodion oneself, but to use that prepared by makers of repute; I usually employ Thomas's or Hardwich's collodion, both of which I have found to be very uniform in quality.

It is desirable to sensitize frequently new batches of collodion, and to determine by experiment from time to time the gradual development and decline of their sensitiveness.

Collodion should not be sensitized until after it has stood for, at least, a week after it has been purchased, and it must then be carefully poured into the mixing vessel without disturbing the sediment which always is present. It must be agitated occasionally for some hours after mixing with the sensitizer, before it is set aside to rest and deposit the new sediment which forms. After standing for a week, it should be carefully decanted for use, to the extent of three-fourths, into a perfectly clean glass vessel.

The glass mixing vessels should invariably, previous to use a second time, be washed out, first with a mixture of equal parts of ether and alcohol, and then with water and pieces of blotting-paper, well shaken up, so as to reduce the paper to pulp; and finally, rinsed out with distilled water, and suspended in a warm place, mouth downwards, to drain and dry thoroughly.

Iodide of cadmium appears, on the whole, to be the best sensitizer for collodion to be used in celestial photography: collodion, prepared with this salt, is not very active when first mixed; hence it differs from collodion prepared with iodide of potassium and iodide of ammonium in this respect, but it gradually acquires a degree of sensitiveness unsurpassed, if equalled, by collodion rendered active with the latter salts, used either alone or mixed with other salts. Collodion, mixed with iodide of potassium, acquires, it is true, great sensitiveness soon after it is prepared, but in a few days it loses in this respect, is moreover continually changing, and is seldom available in celestial photography after standing a month or six weeks; whereas cadmium collodion will retain its qualities for several months. As fresh mixed collodion is certain to produce both white and dark specks in the photograph, as large or larger than the details visible in the picture with a magnifier, it will be seen that a collodion which can be kept for a long time to deposit, without losing in sensitiveness, must be the most valuable; moreover, in collodion mixed with the alkaline iodides there is always an evolution of free iodine which soon impairs the sensitiveness of the nitrate of silver bath by rendering it acid; and for these reasons I generally give the preference to cadmium collodion.

Sometimes collodion exhibits a reticulated structure after the photograph has dried, which materially militates against the beauty of the picture, and prevents its being highly magnified; it occasionally happens that this defect cannot be cured, in which case the collodion should be rejected. I have generally found, however, that this "craping" may be obviated if the collodion be diluted, more or less, with a mixture of two parts of ether and one part of alcohol when it is being sensitized, care being taken to add as much of the solution of iodide in relation to the diluting liquids as would have to be added to an equal volume of collodion.

After using collodion for several evenings, it is well to allow it to stand for some days, and to decant about three-fourths into a fresh vessel.

Before pouring the collodion on to the glass plate, the usual precaution of cleaning away with the fingers any dried collodion from the lip of the containing vessel must be attended to; moreover, each time, just in the act of pouring, a few drops should be allowed to fall to waste on the floor; by attention to these remarks, much vexation will be avoided.

Exposure of the Plate in the Telescope.—On taking the plate from the nitrate of silver bath, it is desirable to drain it well before it is put into the slide, first on the edge of the bath, then on white blotting-paper, shifting its position two or three times, but always keeping the same point downwards. It must be carried to the telescope as quickly as possible, and the picture developed immediately after it has been removed from it.

The sensitized plate rests on angles of pure silver, let into the square plate-holder, or in the circular plate-holder within a ring of pure silver, the face resting on three prominent places. I have found that contact with wood is liable to produce stains which occasionally extend across the plate during the development. The circular plate-holder is entirely of metal, and I would recommend metal holders in preference to those of wood for celestial photography, because they are not liable to warp and become set from damp when left in the observatory. The plate-holder should be wiped with a clean cloth after each operation, and the hands also washed each time before a fresh plate is taken, on which it is intended to pour collodion.

In order to subject the sensitized plate to the action of light when the telescope is used as a Newtonian, I remove a very light cover, previously placed over the mouth of the telescope, and replace it when I wish to discontinue the action; this cover is made of black merino, stretched on a whalebone hoop and is provided with a handle of bamboo. In the direct method, I turn up or down, through an arc of 90°, a little hinged trap, interposed between the great mirror and the sensitive plate. This motion is given by means of a lever fixed on a light axis, supported by the arm which holds the small camera; the axis extending beyond the edge of the telescope tube, and carrying a milled head by which it is turned.

Regulation of the Time of Exposure.—A journeyman-clock, beating seconds distinctly, should be near the telescope, in order that the operator may be enabled to regulate the time of exposure, which requires great nicety with such sensitive chemicals as must be employed.

The time occupied in taking lunar pictures varies considerably; it depends on the sensitiveness of the chemicals, on the temperature, on the altitude of the moon and her phase. An almost imperceptible mist in the atmosphere will sometimes double the time of exposure, but, curiously enough, a bright fleecy cloud passing over the moon scarcely stops any of the actinic rays. I have recently produced an instantaneous picture of the full moon, and usually get strong pictures of the moon in that phase in from one to five seconds. The moon as a crescent, under like circumstances, would require about 20 to 30 seconds, in order to obtain a picture of all the parts visible towards the dark limb.

Development of the Picture.—Of all the developing mixtures tried, I give the preference to the aceto-pyrogallic acid solution, which is generally used in the ordinary proportions; namely, pyrogallic acid, three grains; glacial acetic acid, one fluid drachm; distilled water, three fluid ounces; but, in cold weather, I sometimes reduce the quantity of acetic acid to one half, to render the solution more active. The developing fluid retains its properties for a week or more after mixing. It is desirable to pour out the requisite quantity of fluid

in a small vessel, and to place it in readiness, before the plate is removed from the bath and put into the slide, so as to prevent any delay after the plate has been exposed in the telescope. This precaution obviates the staining which arises sometimes by partial drying of the film.

The addition of nitrate of silver to aid in bringing out the picture must be avoided; pictures thus intensified will not bear any magnifying power, and are comparatively worthless. Hence it will be seen how all-important it is to have the bath and collodion in their most sensitive condition. The negative should not be developed too strongly, as such pictures never copy so well as those moderately but distinctly brought out. Such small photographic pictures as those of Jupiter and Saturn present many obstacles to their development, on account of the difficulty of discerning them during the operation; for the focal image of Jupiter in my telescope, even when the planet is in opposition, is only about $\frac{1}{37}$th of an inch in diameter.

After the development of the picture to the desired point, the further development is arrested by pouring a quantity of water on the plate, and a vessel containing water should be at hand for this purpose.

Fixing the Picture.—By preference I use hyposulphite of soda for fixing; after fixing, the plate is washed under the tap of a cistern of water for a short time, and then examined with a lens. If worth retaining, the epoch of the picture, and other particulars are recorded at the back with a writing diamond. The plate is then washed again, front and back, in a stream of water, and placed face upwards on a tripod stand, duly levelled; rain-water* is poured on the collodion, and from time to time this is poured off and fresh poured on, in the meantime other photographs are proceeded with. After half an hour or more, the plate is thoroughly washed in a stream of rain-water, and placed edgewise on blotting-paper against the wall, to drain and dry.

Varnishing.—The next morning, the negatives are warmed before a fire, and varnished with Sœhnée's varnish†, which is the only description I have found to stand. I am careful to filter the varnish before using; otherwise specks might be transferred to the photograph. It is very desirable to varnish the plates as soon as they are dry, for, if left unvarnished for any length of time, they can never be varnished evenly.

Desiderata in the Machinery for driving the Telescope.

As in the production of celestial photographs some seconds of exposure are requisite, it is essential to have a clock-work driver to the telescope, which works uniformly and smoothly, and which is also capable, when lunar pictures are to be taken, of ready adjustment to the ever-varying lunar time. Lunar time, it will be recollected, differs from sidereal time, in consequence of the moon's variable motion in her orbit in a direction opposite to that of the apparent diurnal movement of the stars. A driving clock, if adjusted to follow a star, must be retarded therefore, more or less, in order to follow the moon. In my own telescope, this is at present effected by altering the length of the conical pendulum or friction governor, thus altering the time of its rotation (or double beat), and this plan, or some modification of it, is universal. My experience, however, has pointed out several inconveniences in thus changing the speed of the governor or pendulum, and it is my intention to make such alterations in the construction of the clock as will enable me

* In preparing the bath and developing solutions, distilled water must be employed, but filtered rain-water answers very well for washing the photographs.

† Sold by Messrs. Gaudin, 26 Skinner Street, London.

to alter the going of the telescope without changing the rate of the pendulum. This I propose to do by substituting an arrangement, similar to that known in mechanism as the disc and plate, for the wheel-work now connecting the machinery of the clock with the pendulum; the disc and plate being capable of producing a variable motion, according as the disc is nearer to or farther from the centre of the plate. The pendulum will, by the proposed plan, be driven by frictional contact, and, having employed this system in other machinery, I feel persuaded that its application to the clock-driver will not be attended with difficulty or inconvenience.

The moon, besides her motion in right ascension, has also a motion in declination, which is greatest when she is situated in one of the nodes formed by the intersection of the plane of the moon's orbit and the plane of the earth's equator, and is least when situated 90° from these nodes, where it vanishes. As this motion is at times very considerable, it is evident that, with a telescope made only to rotate round the polar axis, the best results will be obtained, all other circumstances being alike, when the motion in declination is at zero. Assuming that, on the average, 15 seconds are necessary for taking a lunar photograph, the moon may have shifted upwards of 4″ of arc in declination during that period; and evidently many details would be lost and the others considerably distorted. In order to ensure the most perfect results under all circumstances, it is desirable to give a movement to the declination axis of the telescope simultaneously with the movement of the polar axis. Hitherto, so far as I am aware, no means have been devised to effect this, but the requisite adjustable motion might be transmitted by means of the disc and plate above described, from the driving-clock, although its pendulum moves with a uniform velocity.

Lord Rosse's Method.—In my original method of taking the pictures by means of the sliding eye-piece before spoken of, both motions in right ascension and declination were provided for by adjusting the slide in the diagonal parallel with the moon's apparent path. Lord Rosse, at a subsequent period, applied a clock-movement to such a slide, and made some experiments in celestial photography*; but, the telescope being required for other special purposes, it appears that they were not long continued. This motion of the plate-holder does not meet all the exigencies of the case, but if one of his magnificent reflectors were arranged to move bodily along a guide adjustable in the direction of the moon's path, by means of some such mechanism as I have alluded to, I believe that lunar pictures might be produced of exquisite beauty, because defects in the collodion film and the glass plate would be of less consequence than with telescopes of shorter focal length, the image being larger in the ratio of focal length; for example, even with the three-foot instrument it would be 3 inches in diameter.

Degree of Perfection hitherto attained in Lunar Photography.

In my own telescope, the picture of the moon is only about $1\frac{1}{10}$in. in diameter; it might be suggested that the image could be enlarged by means of a combination of lenses before reaching the sensitized plate, but this would have the effect of prolonging the time of exposure, and moreover introduce the disadvantages of the refracting telescope, and the result would not be so good, for even if the moon's motion in declination were followed automatically, still the outstanding atmospheric disturbances before alluded to would remain†. Indeed, if the aperture of the telescope could be considerably increased in relation to its focal length, much finer pictures would be procured, because the time of exposure would be shortened. In practice it

* Monthly Notices of the Roy. Ast. Soc. vol. xiv. p. 199.
† Ibid. vol. xviii. p. 17.

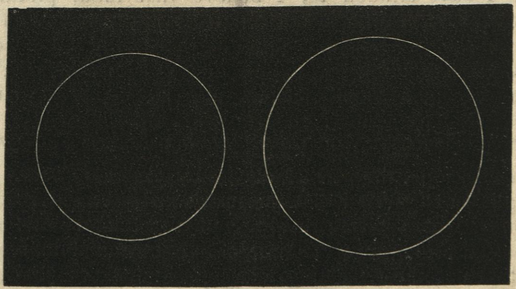
has been found preferable not to magnify the focal image, but to take enlarged positive copies on glass direct from the original negative, by means of an enlarging camera, and in this way the impressions, 8 inches in diameter, exhibited at the Meeting were produced.

In making positive copies, some of the more minute details are, unfortunately, always lost, for no means exist by which enlarged positive copies can be produced showing all the treasures of the original negative; a perfect enlarging lens being still a desideratum*. As an instance may be cited the streak in the lunar disc, which Mr. James Nasmyth has called "the railroad," indicated in Beer and Mädler's map as a straight line to the east of the crater Thebit between latitude 19° and 23° south, and between longitude 7° and 9° east. In the photograph it is shown to be a crack in the lunar crust with an irregular outline, and the eastern edge is perceived to be depressed below the western, which forms a perpendicular cliff. This, although sharply defined in the negative, is frequently lost in positive copies. For the examination and micrometrical measurement of the minuter details which celestial photography is capable of furnishing, recourse must still be had to the original negative.

Notwithstanding the disturbances which arise from the atmosphere, minute irregularities in the driving-clock, and the want of means for following the moon's motion in declination, I have obtained pictures of the moon that bear examination with the three-inch object-glass of a compound microscope magnifying about $16\frac{3}{4}$ times, and which show with good definition details occupying a space less than two seconds in each dimension. Two seconds are equal to about $\frac{1}{860}$th of an inch on the collodion plate in the focus of my telescope, and in the finest photographs, details occupying less than $\frac{1}{1000}$th of an inch are discernible with the three-inch object-glass; hence much valuable work has already been accomplished. A second on the lunar surface at the moon's mean distance being about one mile (1·149 mile), it will be evident that selenological disturbances, extending over two or three miles, would not escape detection, if such occur, provided photographs continue to be taken for a sufficiently long period.

Lunar Phenomena recorded by Photography.

Full Moon.—Variations of apparent Diameter.—By the delineation of our satellite, photography brings out palpably several phenomena which, although



well known, are not always present to the mind; for example, about every 29 days it is stated that there is a full moon, but we see by the photographic picture that there never is a full moon visible to us, except just before or just

* May 1860.—As these sheets are passing through the press, the author has been informed by Mr. Dallmeyer (son-in-law of the late Mr. Andrew Ross) that he has brought his investigations on this subject to a successful termination, and that he has just produced enlarging and diminishing lenses which copy without any sensible distortion or dispersion.

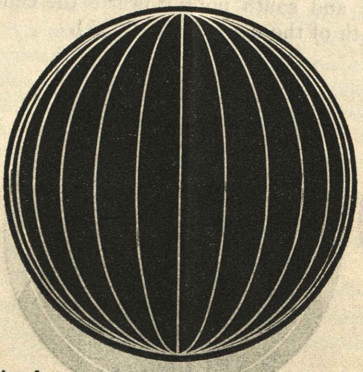
after a lunar eclipse, or at all events except when the sun, earth, and moon are very nearly in the same plane; at all other periods of the full moon we are unfavourably situated for seeing the whole of the illuminated hemisphere. Moreover, the different apparent diameter of the moon at various times, dependent on her distance from the earth, comes out in unmistakeable prominence in a collection of photographs; for the pictures taken with my reflector vary in diameter from one inch to one inch and nearly two-tenths (1·0053 inch to 1·1718 inch, being at the moon's mean distance 1·0137 inch).

When positive enlarged copies are made, it is easy to obtain all the pictures of exactly the same dimensions by the adjustment of the distance of the negative to be copied from the lens of the camera; and my enlarging camera is furnished with screws to facilitate the adjustment of the distance of the object to be copied, and also that of the focusing screen.

Libration.—We are familiar with the terms "diurnal libration," and libration in "latitude" and "longitude," yet it is difficult to realize the great amount of disturbance in the aspect of the moon's disc, and the direction of the displacement from the mean position which these several causes produce unless aided by photography, when we see them palpably before us.

The diurnal or parallactic libration never exceeds 1° 1′·5; the direction of the displacement in the markings on the lunar disc which it produces is variable, and is dependent partly on the position of the observer.

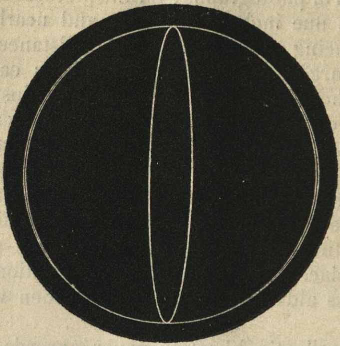
The poles of the moon at the epoch of Mean Libration are situated in the periphery, and the equator and all parallels of latitude are straight lines; the circles of longitude being more or less open ellipses, varying from a straight line in the centre to a circle at the periphery. This occurs when our satellite is either in perigee or apogee (when the libration in longitude is at a minimum), and she is also situated in one of the nodes of her orbit (when the libration in latitude vanishes): the nodes, apsides, and moon would, under these circumstances, be in the same line.



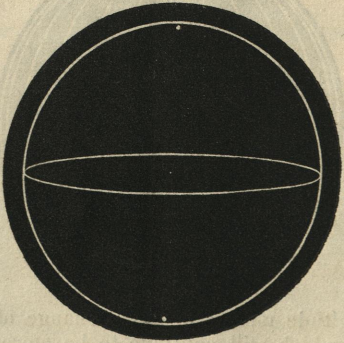
Libration in Longitude merely causes a change of place in the various circles of longitude, which still continue to be more or less open ellipses; the parallels of latitude straight lines.

Those lunar craters, however, situated on the central meridian at the epoch of mean libration would be on a straight line, but, at the periods of maximum eastern or western libration, they would be seen arranged on a semi-ellipse, whose conjugate diameter is 0·1377, the moon's diameter being unity. Therefore a point at the centre of the moon's equator becomes shifted by the sum of the librations to the east and to the west to the extent

of more than $\frac{1}{8}$th of the moon's diameter, namely 0·0688 to the east, and the same quantity to the west of the mean position. On account of perspective, the effect of libration in longitude is much less apparent on the eastern and western peripheral meridians, which shift towards the centre by a quantity equal only to $\frac{1}{229}$th of the moon's diameter (0·0048).

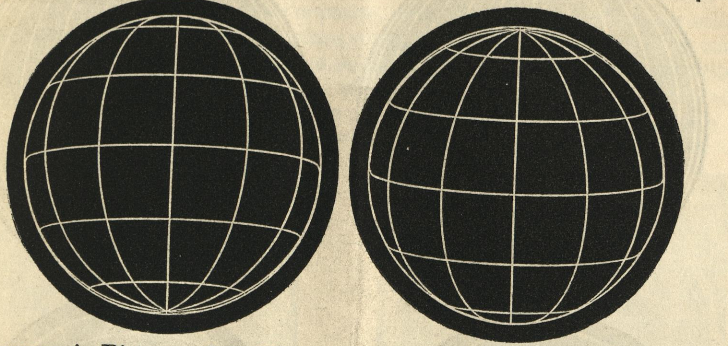


The equator and its parallels, which at the period of mean Libration in Latitude were straight lines, become more or less open ellipses under other circumstances; the ratio between the conjugate and transverse axes of all the parallels being constant for a given inclination of the lunar axis. At a maximum libration in latitude the equator becomes an ellipse, whose conjugate axis is 0·1181; the transverse axis being equal to the diameter of the moon considered as unity: so that a point in the centre of the equator is shifted 0·059 of the diameter to the north or to the south by a maximum northern or southern libration, and will move by the sum of these librations to an apparent extent of $\frac{1}{9}$th of the diameter of the lunar disc. The apparent motion of the north and south poles towards the centre is on account of perspective only $\frac{1}{286}$th of the diameter (0·0035).



Libration in latitude also causes a change in the ellipses which delineate the meridians, causing an inclination of their axes to the line joining the poles, and also a change in the ratios of their transverse to their conjugate axes. For example, the meridian distant 7° 55′ from the centre (this being the position of central meridian at a maximum libration in longitude) would have its transverse axis inclined 0° 56′·3 to the pole, the conjugate axis being no longer 0·1377 but 0·1368 of the transverse. The peripheral meridians

would no longer be semi-circles, but semi-ellipses, whose conjugate diameter is equal to 0·9965, and whose transverse diameter is inclined 90° to the pole.

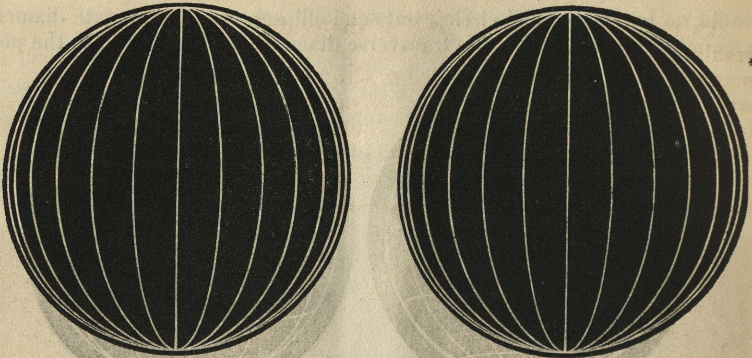


Stereoscopic Pictures of the Moon.—Taking advantage of the libration, we may, by combining two views taken at sufficiently distant periods, produce stereoscopic pictures which present to the eyes the moon as a sphere. It has been remarked by the Astronomer Royal, that such a result is an experimental proof of the rotundity of our satellite. A dispute has been going on between photographers as to the proper angle for taking terrestrial stereoscopic pictures, and I infer that one side of the disputants would consider my arrangement of moon-pictures to produce stereographs unnatural, because under no circumstances could the moon itself be so seen by human eyes; but, to use Sir John Herschel's words, the view is such as would be seen by a giant with eyes thousands of miles apart: after all, the stereoscope affords such a view as we should get if we possessed a perfect model of the moon and placed it at a suitable distance from the eyes, and we may be well satisfied to possess such means of extending our knowledge respecting the moon, by thus availing ourselves of the giant eyes of science.

It does not follow as a matter of course that any two pictures of the moon taken under different conditions of libration will make a true stereoscopic picture; so far from this being the case, a most distorted image would result, unless attention be paid first to the selection of the lunar pictures, and then to their position on the stereoscopic slide. It is possible to determine beforehand, by calculation, the epochs at which the two photographs must be taken in order to produce a stereoscopic picture; but so many circumstances stand in the way of celestial photography, that the better course is to take the lunar photographs on every favourable occasion, and afterwards to group such pictures as are known to be suitable.

A little consideration of what has been before stated will show that two lunar pictures, differing only by libration, either in longitude or in latitude, will give a true stereoscopic effect, provided the angular shifting is sufficiently great.

On the other hand, if the two pictures differ both by libration in latitude and in longitude, they will give a true stereoscopic picture provided they satisfy the following condition. Suppose a point in the centre of the equator, when the moon is in a mean state of libration, has become shifted at the epoch of picture A in any given direction, and let an imaginary line pass through that point and the centre of the lunar disc, if at the epoch of picture B the point lies anywhere in the direction of that line, then a true stereograph will be obtained, provided the two pictures be suitably placed in the stereoscope.



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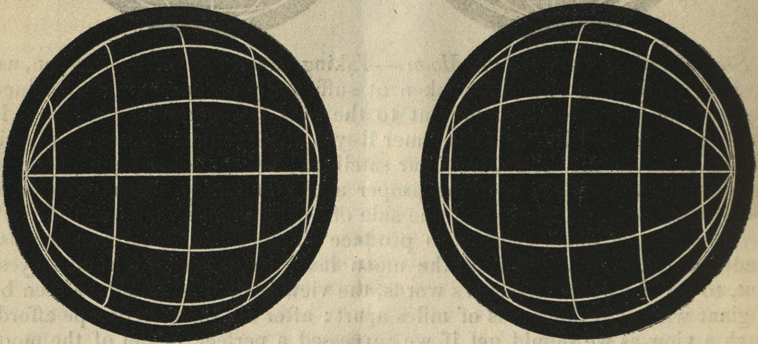
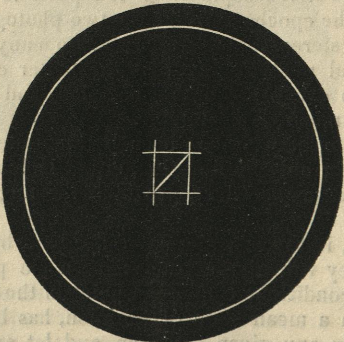


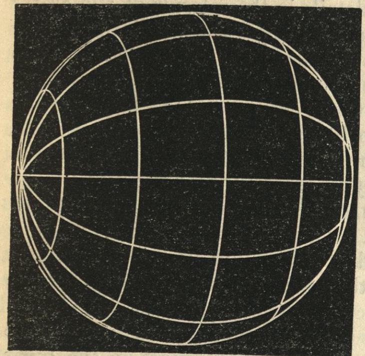
Assuming the space between the eyes to be $2\frac{3}{4}$ inches, and the nearest distance for distinct vision to be about 10 inches, we find $15° 48'$ as the maximum stereoscopic angle. The possible shifting of the position of an object on the lunar disc from east to west by libration in longitude may amount to $15° 50'$, which is almost identical with the assumed maximum stereoscopic angle, and the displacement from north to south, by libration in latitude, never exceeds $13° 34'$, which falls within that angle. By the joint

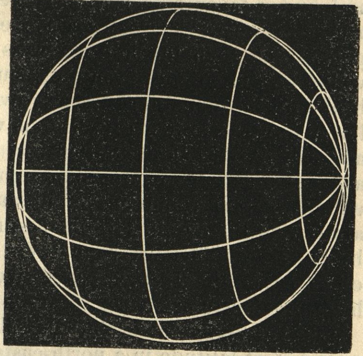


effect of a maximum libration in longitude and latitude, a point on the lunar surface may, however, be shifted nearly 21°, which is greater than that under which an object could be viewed by the eyes.

* The centres of these diagrams should be $2\frac{3}{4}$ inches distant to give a stereoscopic picture.

An exaggerated protuberance of the central portion of the moon might result from the combination of two pictures obtained, at two epochs of maxima, in directions diagonally opposite, and the moon would appear somewhat egg-shaped. We may convince ourselves that this would be the case, by viewing, in the stereoscope, two suitably drawn orthographic projections of the lines of longitude and latitude of the sphere, especially if we purposely exaggerate the angle still more; for example, if we make the libration in latitude the double of what it is in reality.

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At the meeting at Leeds last year, there were exhibited some of my stereoscopic lunar pictures 8 inches in diameter, and an apparatus constructed expressly for viewing them. The instrument is of similar construction to Wheatstone's reflecting stereoscope; but, the objects being transparent, the usual arrangements and adjustments are considerably modified. Prisms with slight curvatures worked on their surfaces are employed, instead of mirrors, for combining the pictures which can be revolved and moved horizontally and vertically in order to place them in the true position. The effect of rotundity is perfect over the whole surface; and parts which appear like plane surfaces in a single photograph, in the stereoscope, present the most remarkable undulations and irregularities.

Light and Shade in the Photograph as compared with that of the Optical Image.—Portions of the moon, equally bright optically, are by no means equally bright chemically; hence the light and shade in the photograph do not correspond in all cases with the light and shade in the optical picture. Photography thus frequently renders details visible which escape observation optically, and it therefore holds out a promise of a fertile future in selenological researches; for instance, strata of different composition evidently reflect the chemical rays to a greater or less extent according to their nature, and may be thus distinguished†. The lunar surface very near the dark limb is copied photographically with great difficulty, and it sometimes requires an exposure five or six times as long, to bring out completely those portions illuminated by a very oblique ray, as others, apparently not brighter, but more favourably illuminated:—the high ground in the Southern hemisphere of the moon is more easily copied than the low ground, usually called seas, which abound in the Northern hemisphere: from these circumstances I ventured, in another place‡, to suggest that the moon may have an atmo-

* These diagrams should be 2¾ inches from centre to centre to give a stereoscopic picture.

† Professor Phillips has also noticed this difference between the visual and actinic brightness of portions of the lunar surface. Report of the Brit. Ass., 1853, Section A. p. 16.

‡ Monthly Notices Roy. Ast. Soc. vol. xviii. pp. 18 and 111.

sphere of great density, but of very small extent, and that the so-called seas might be covered with vegetation. This idea respecting a lunar atmosphere has, I am inclined to believe, received some confirmation from a recent observation of Father Secchi's, that the lunar surface polarizes light most in the great lowlands and in the bottoms of the craters, and not appreciably on the summits of the mountains.

Radiating Lines in the Moon's Disc.—The mountain peak in the centre of Tycho, about one mile in height, is very distinct in the photographs, and under favourable circumstances the details in the interior of the crater are well shown. The external slopes under all illuminations are darker in the photograph than the internal walls and the bottom of the crater. Tycho would appear to have been the focus of a wonderful disturbing force which broke up the moon's crust nearly over the whole visible surface, for radiating lines converge in that conspicuous volcano, like so many circles of longitude, and cannot fail to attract attention. Several theories have been suggested to account for these radiating lines; by studying a series of photographs taken under different conditions of illumination one becomes convinced that they are due to furrows in the lunar surface*. They are in some cases overlaid by craters which must have been formed at a subsequent period; and in other cases the furrow has dislocated the crater, which must therefore have previously existed.

One very remarkable Furrow fully fifty miles broad, extending from Tycho over 45° of latitude in a north-easterly direction, is the deepest on the lunar surface. The eastern ridge of this furrow skirts Mount Heinsius, and the western ridge extends to Balliald and Euclides, where the furrow becomes very shallow, but is traceable as far as Kepler.

Another conspicuous furrow runs from Tycho in a north-westerly direction nearly up to the northern limb of the moon, and extends over 100° of latitude, passing through Menelaus and Bessel in the Mare Serenitatis through a crater (marked E in Beer and Mädler's map) at the head of a promontory running into the Lacus Somniorum, when it is crossed by another furrow extending tangentially to the Apennines. The intersection of these streaks resembles the letter X, and indicates another focus of disturbance near the crater E in north latitude 35° and west longitude 24°. The main furrow from Tycho continues on through the crater Plana, leaving Burg untouched on the east, and terminates to the south of Strabo in north latitude 60° and west longitude 45°.

A furrow best seen about the full moon or a little after, extends from Tycho, though not quite continuously, through the Mare Nectares, traversing the crater A on the west of the crater Theophilus; sweeping in a curve eastward, it leaves Tarantius on the west, and crosses the bright crater Proclus, forming an eastern tangent to Berzelius. Leaving Endymion to the south-east, it forms the southern boundary of the Mare Humboldtianum in north latitude 70° and west longitude 90°, having traversed 110 degrees of latitude.

A remarkable focus of dislocation exists in the Mare Fœcunditatis in latitude 16° south and longitude 50° west, which also, by the crossing of the lines of disturbance, looks like another letter X in the photograph.

The radiating lines of dislocation are so numerous that it would be impossible, within reasonable limits, to describe any but the principal ones; I should state, however, that they must not be confounded with the sinuous lines which radiate from Copernicus and other lunar craters, and which are markedly different in character and origin.

* Monthly Notices Roy. Ast. Soc. vol. xviii. p.111.

Value of Photography in the Production of Selenographical Charts.

Pictures of Copernicus may be cited as an example of the aid photography would afford in mapping the lunar surface: this becomes especially apparent when an original negative is examined with a compound microscope. The details brought out in and around this crater in a fine negative by a three-inch object-glass are quite overwhelming from their number and variety. Not only the elaborate network of sinuous radiating lines on the exterior of Copernicus, but also the terraces in the internal walls of that wonderful volcano, the double central cone, the curvature of the sole of the crater, and its polygonal form, all appear in vigorous outline.

Again, photographs of the Apennine ridge, under different illuminations, are among the most beautiful of the results of the application of the art to selenography; it renders conspicuously evident many details of tint and form in that extensive ridge, which would escape the most careful scrutiny of the visual picture unless attention was previously directed to them by the photograph. Unaided by photography, it would indeed be almost hopeless to attempt a correct representation of that wonderful chain of mountains, affected as its form is, on account of its vast extent, by libration, and also on account of the changes in the shadows occasioned by the varying direction of the illumination. Aided by my collection of pictures, I hope to be able to acquit myself in a creditable manner of the trust I have accepted, and to contribute that quota of the lunar surface allotted to me by the British Association.

If, at a future period, the entire lunar surface is to be again mapped down, photography must play an all-important part, for, as Messrs. Beer and Mädler remarked in their invaluable work on the moon, it is quite impossible to complete even a tolerably satisfactory representation of our satellite in those rare and short moments when the mean libration occurs. One is therefore obliged to observe the moon under many different conditions of libration, and to reduce each measurement and sketch to the mean before the mapping can be proceeded with; for not only the position, but also the shape of the objects is altered by libration even from one evening to another. On the other hand, with photography at command, we may obtain in a few seconds pictures of the moon at the epochs of mean libration, and accumulate as readily a great number of records at other times. The latter would furnish, after reduction to the mean, a vast number of normal positions with which the more minute details to be seen with the telescope might be combined.

By means of a microscope, with a camera-lucida prism fixed on the eye-piece, enlarged drawings are readily made of different dimensions by varying the magnifying power and the distance of the paper from the eye-piece; with a normal magnifying power of seventeen times linear, drawings of lunar craters can be conveniently made of the exact scale used by Beer and Mädler for the large edition of their maps, by simply placing the drawing paper at the proper distance. These drawings may then be rendered more complete from time to time by filling in the minuter details by actual observation, and in this way materials accumulated for a selenographical chart such as even the skill and perseverance of a Mädler could not hope to accomplish.

Photography of the Planets.

Occasionally I take photographs of the fixed stars, and among others have made pictures of the double star Castor, but, as a general rule, I leave the fixed stars under the able custody of the Harvard Observatory, Cambridge, U.S., and devote my attention chiefly to the moon, making, however, from

time to time, photographs of the planets under the rare circumstance of a quiescent state of the atmosphere.

In photographing the planets, it is sometimes advantageous to take several pictures on the same plate; this can be conveniently done with my telescope, because the driving clock is connected with the telescope by means of a peculiar spring clutch formed of two face-ratchet-wheels. When one picture has been taken, the image is shut off, and the ratchet disconnected, so that the telescope remains at rest, the clock continuing to go. During the interval of rest, which interval is conveniently regulated by the passage of a certain number of teeth of the moving half of the clutch, the planet will have moved through a short distance in its diurnal arc; and when the clock has been again thrown into gear, the image will fall on another part of the plate. In this way, four or five images of a planet, for example Jupiter, may be obtained in a very short time. These images are arranged at equal distances along an arc of right ascension, and afford a ready means of determining the angle of position of the belts, &c., as was proposed by the late Professor Bond with respect to the angle of position of double stars.

Relation of Actinic Power to Luminosity.—I have alluded before to the difference in the optical and photographic picture of the moon; another very remarkable result of photography is the great difference which has been proved to exist in the relation of actinic power to luminosity of the various celestial objects. For example, the occultation of Jupiter by the moon, on November 8th, 1856, afforded an excellent opportunity for comparing the relative brightness of our satellite and that planet. On that occasion, Jupiter appeared of a pale greenish tinge, not brighter than the crater Plato, and, according to my estimate, of about one-third the general brilliancy of the moon; but the actinic power of Jupiter's light was subsequently found to be equal to fully four-sixths or five-sixths of that of the moon*.

Saturn required twelve times as long as Jupiter to produce a photograph of equal intensity on an occasion specially favourable for making the experiment; yet I obtained a picture of Saturn together with that of the moon in 15 seconds on May the 8th of the present year, just as the planet emerged from behind the moon's disc. The picture of the planet, although faint, is sufficiently distinct to bear enlarging.

With two pictures of the moon and a planet (or a bright fixed star) taken at a short interval at the period of an occultation, or near approach of a planet or star by the moon, we may obtain a stereoscopic picture which would make the moon (seen, of course, as a flat disc) appear nearer than the planet or star.

Stereoscopic Pictures of the larger Planets.—Photographs of the planet Jupiter, although far inferior hitherto to the optical image seen with an eye-piece, show the configuration of the belts sufficiently well to afford us the means of producing stereoscopic pictures; all that is necessary is to allow an interval to elapse between the taking of the two pictures, so as to profit by the rotation of that planet on its axis. In the space of 26 minutes the planet will have rotated through the $15° 48'$ necessary to produce the greatest stereoscopic effect.

Mars would, in 69 minutes, have rotated through the same angle, and, as his markings are very distinct, we may hope to obtain stereoscopic views of that planet.

The markings on the other planets are too faint to hold out a promise of similar results. Although this is the case with respect to Saturn, the ap-

* Monthly Notices Roy. Ast. Soc. vol. xviii. p. 55.

parent opening and closing of his ring as he revolves round his orbit affords us the means of obtaining a stereoscopic picture. Thus photographic reductions of the two original drawings which I made in November 1852 and March 1856 placed in the stereoscope (in such a manner that the major axes of the rings are at right angles to the line joining the eyes) give a picture in which the planet appears as a spheroid encircled by his system of rings, although the difference of position of the two pictures amounts only to 7°. And there is no reason why we may not obtain a stereoscopic picture composed of photographs taken actually from the planet.

Loss of the Actinic Rays by Reflection.

Until very lately, my celestial photographs were obtained by placing the sensitized plate at the side of the tube, opposite to the diagonal reflector of the Newtonian telescope; hence the light, before it reached the plate, was twice reflected. As it requires a very firm support for the diagonal speculum, of even a 13-inch mirror, to prevent vibration, the arm carrying this mirror was firmly screwed to the side of the telescope-tube, and rendered immoveable; I could not therefore make experiments in taking the pictures direct, that is to say, with the light only once reflected, without some alteration to the diagonal holder. I have, however, within the last few months, contrived an apparatus which permits of the ready removal and replacement of the diagonal mirror without impairing its stability, and celestial pictures are now taken at will, either direct or reflected out at the side of the tube; moreover it requires but a minute to change the apparatus to produce either result. With these means, I am able to make experiments to determine the relative actinic intensity of the light after one or two reflections. The experiments are still in progress, and have been begun so recently, that it is scarcely advisable to hazard a conjecture as to the result; but I may say that I am disappointed as to the increased rapidity of the production of a celestial picture by the direct method over the twice-reflection method; and I am inclined to infer that Steinheil's result as to the loss by reflection from speculum metal of the luminous ray does not hold as regards the actinic ray.

In concluding the first part of this report, I would remark that to photograph the moon continuously is a laborious undertaking, and affords full occupation for one observer, who must not fail to pay unremitting attention to the condition of the various chemicals employed, so as to be always prepared for a fine night with such as will work. I would therefore strongly urge the claims of this new branch of astronomical science to a more extended cultivation than it has hitherto received, with the conviction that it will require the ardent co-operation of many astronomers to develope fully its rich resources.

PART II.—*Photoheliography at the Kew Observatory.*

The Photoheliograph erected at the suggestion of Sir John Herschel* at the Kew Observatory has already been described in the Reports of the Kew Committee, 1856–57† and 1858‡, and in the Report for the present year.

It will not, however, be out of place to give some account of the instrument as at present actually in use, for, whilst part of the apparatus originally

* Report Brit. Assoc. 1854, p. xxxiv. † Id. 1857, p. xxxiv. ‡ Id. 1858, p. xxxiv.

provided has been found unnecessary, it has been deemed desirable to make some additions to the instrument from time to time.

The object-glass of the photoheliograph, it will be remembered, is of $3\frac{4}{10}$ inches clear aperture and 50 inches focal length, but the whole aperture is never used; it is always diminished more or less, and generally to about 2 inches, by a stop placed in front of the object-glass. The focal image of the sun at the mean distance is 0·466 inch. The focal image is not, however, received directly on the sensitive plate, as in the case of taking lunar and planetary photographs, but is enlarged before it reaches it by means of a secondary combination of lenses (an ordinary Huyghenian eye-piece), which increases the picture to about 4 inches in diameter, thus magnifying the image about eight times linear, and diminishing the intensity of the light 64 times.

The object-glass (made by the late Mr. Ross) is specially corrected to ensure the coincidence of the visual and chemical foci; but, as might be anticipated, the rays, after passing through the secondary lens, are in some degree dispersed, and this coincidence of foci no longer exists. It required some considerable time to determine exactly the position of the actinic focus; ultimately it was proved, after numerous trials, that the best photographic definition is obtained when the sensitized plate is placed from $\frac{1}{10}$th to $\frac{1}{8}$th of an inch beyond the visual focus, and that this adjustment must be modified to a slight extent according as more or less of the aperture of the object-glass is employed.

Difficulties of Photoheliography.—Whilst in lunar and stellar photography many of the obstacles to be overcome arose from the deficiency of photographic power in the unenlarged focal images of those celestial objects, the difficulties which have stood in the way of producing good sun-pictures arose in a great degree from the incomparably greater brilliancy in the sun's image, even when its intensity was considerably lessened by stopping off a large portion of the object-glass, and magnifying the diameter of the image very greatly. In order to overcome these obstacles, recourse was had at an early period to the less sensitive media than wet collodion, such, for example, as are used in the albumen and the dry collodion processes. None of these attempts were, however, productive of sufficiently promising results to encourage the pursuit of the trials in this direction, and I may mention that I made simultaneous experiments in taking unenlarged pictures in the focus of my reflector, on dry collodion and albumen, with no better result. The surfaces in these processes are indeed very rarely sufficiently free from impurities for the delineation of such minute objects as solar spots, and the processes themselves present disadvantages which render them inapplicable to photoheliography.

After many unsuccessful trials a return was at last made to the collodion process. Former experience having shown that the shortest exposure possible with the means then at command produced only a solarized image, in which all trace of the sun-spots was obliterated, recourse was had to the interposition of yellow glass between the principal and secondary object-glasses, with the view of diminishing the actinic intensity of the sun's image; nevertheless only burnt-up pictures were produced.

Instantaneous Apparatus.—It will be evident, therefore, that, for the successful employment of a medium so sensitive as wet collodion, it was absolutely necessary to contrive some means for reducing the time of its exposure to the sun's influence to an extremely small fraction of a second. Any apparatus placed in front of the object-glass, it was conceived, would have the disadvantage of cutting off the aperture by successive non-symmetrical portions, and of producing an image less perfect than when the exposed portion of the object-glass remained always concentric and circular. On the other hand, it was

seen that a slide with a rectangular opening, if caused to move across the tube in front of the sensitized plate, would in no way distort the picture, but would merely stop off a portion of it, and have the effect, as it moved along, of allowing each part of the sun's image to act in succession on different parts of the collodion, and there to record itself; but a rapidly moving object close to the collodion-plate is so liable to cause a disturbance of dust, and its consequent lodgement on the collodion-film, that the carrying out of the idea in this manner was given up.

The late much-lamented Director of the Observatory, Mr. Welsh, suggested the plan which was ultimately adopted with success; instead of placing the sliding apparatus close to the collodion-plate, he proposed that it should be made on a smaller scale and fixed as near the plane of the primary focus as possible. Mr. Beckley has skilfully carried out this suggestion; so that the apparatus answers its intended object most perfectly, and the production of a solar picture is now at least as easy as that of a lunar picture. The sliding plate is very light, and moves so freely, that it does not, while in motion, disturb the telescope in the slightest degree; it is drawn downwards by means of a spring of vulcanized caoutchouc, and as soon as it is released it shoots with great rapidity across the field. The sliding plate has two apertures, one circular, and sufficiently large to permit of the passing of all the rays; this is used for the purpose of focusing on the screen, and also in observing contacts of the sun's limb with the wires to be hereafter described. The second aperture is square, and is fitted with a sliding piece actuated by a screw, which projects beyond the telescope tube; by means of this screw the aperture may be completely closed or readily reduced to a slit of any required width, equal to or smaller than the side of the square opening, a divided scale being affixed to the screw for that purpose.

Previous to taking a picture the sliding plate is drawn up just so high that an unperforated part of it completely shuts off the sun's image; the plate is held in this position by means of a small thread attached to it at one end, and looped at the other, the loop being passed over a hook on the top of the tube. When the picture is about to be taken, the retaining thread is set on fire, and the rectangular aperture, as soon as the sliding plate becomes released, flashes across the axis of the secondary object-glass, thus allowing the different parts of the sun's image to pass through it in succession, and to depict themselves, after enlargement, successively on the collodion-plate. Although the time of exposure is so short as to be scarcely appreciable, yet it is necessary to regulate its duration; and it is therefore controlled by adjusting, 1st, the strength of the vulcanized caoutchouc spring; 2nd, the width of the aperture. In practice, the opening is usually varied between $\frac{1}{10}$th and $\frac{1}{20}$th of the diameter of the sun's focal image.

No driving Machinery needed, except at the period of a Total Eclipse.—It will be seen from the foregoing description that the clock-work driving apparatus, described at page xxxv. of the reports for 1857, can be of no service, because the photograph is taken in so small a fraction of time that no appreciable distortion of the sun's image would result in the interval by allowing the telescope to remain at rest. So rapid is the delineation of the sun's image, that fragments of the limb, optically detached by the "boil" of our atmosphere, are frequently depicted on the collodion, completely separated from the remainder of the sun's disc; more frequently still from the same cause the contour of the sun presents an undulating line.

Although the clock-work driver is unnecessary for the daily work of the photoheliograph, it may prove of great value on the rare occasions of a total solar eclipse. It is to be hoped that it will enable the contemplated expedi-

tion to Spain, in July of next year, to obtain a photographic record of the feeble light of the Corona and the Red Flames; but it is by no means certain that their light will be sufficiently intense for that object. Even a failure, however, will prove of some value, for it will show that the image of these phenomena, when enfeebled by an enlargement of eight times linear, possesses too little actinic power to imprint their outline on a collodion-plate in a given number of seconds; and thus data will be furnished for a future period.

It is desirable that other astronomers should endeavour to obtain photographs of these data by placing the sensitized plate directly in the focus of the telescope.

In taking photographs with the Kew Photoheliograph, the telescope, clamped in declination, is placed a little in advance of the sun, and then clamped in right ascension; the thread is set on fire as soon as the centre of the sun coincides with the axis of the instrument. In order that the operator may know when this is the case, a secondary camera or finder is fixed on the top of the pyramidal tube of the telescope*. This finder consists of an achromatic lens of long focus, which is so placed as to throw an image of the sun on to a plate of brass fixed vertically near the lower or broad end of the tube, and consequently in a convenient position for the operator to see both the image and the retaining thread which holds the slide. The brass plate has ruled on it several strong lines, two of which are just so far apart and so situated as to form tangents to the sun's limb when the image is exactly central; a lighted match, held in readiness, is at this precise moment applied to the thread, and the slide immediately flashes across the secondary object-glass.

Position Wires.—The position of the solar spots in respect to a normal point is determined by placing a system of wires in a certain known position in the telescope. Originally the wires were four in number, two being fixed at right angles to the other two, the distance between each pair being somewhat less than the semidiameter of the sun; so that when one wire of each pair was situated near the sun's centre the other cut off a small arc at the limb. The position of the wires was such that the one pair was parallel to a circle of declination.

Some inconvenience was occasionally experienced in consequence of one or other of the four wires obliterating a solar spot; hence an alteration is now being made in the apparatus for holding the wires. Instead of attaching them to a fixed diaphragm placed between the two lenses of the secondary object-glass, they will be fastened to a sliding diaphragm with two apertures; across one of the apertures only will be fixed the wires, so that a photograph may be taken either with or without them. No appreciable distortion in the photographic image of the wires can be detected.

The wires will be two in number; they will cross each other at an angle of 90°, and form an angle of 45° with a circle of declination. This system of wires is the same as that proposed by Mr. Carrington and used in his observations of solar spots. It is intended when the apparatus is complete to observe the contacts of the sun's limb with the wires as it passes them in succession each day before commencing a set of photographs, and also immediately after completing them. In order to observe these contacts, the image of the sun and wires will be received on the ground-glass focusing plate, and the times of the several transits noted by viewing the image of the sun and wires through the plate. One photograph will in all cases be taken with the wires, and two or three without the wires, in order to secure all the details possible, as well of the faculæ as of the spots.

Degree of perfection attained. Stereoscopic pictures of the Sun.—By over-

* Report Brit. Assoc. 1857, p. xxxv.

exposure of the collodion the faculæ first disappear, then the penumbræ round the spots, and lastly the spots themselves. In the photograph the difference in the intensity of the sun's limb and central portions is very marked, but an over-exposure prevents also this from being seen in the photograph. The solar spots and faculæ delineated by the Kew Photoheliograph bear examination with a lens of moderate power, and show details not visible to the unassisted eye. The faculæ and spots are sufficiently marked to make the sun appear globular when two views taken at a sufficient interval are grouped together in the stereoscope, as will be seen by the slides now before the Meeting. There is not the same difficulty in obtaining stereoscopic pairs of views of the sun as there is in the case of the moon, because any two views taken at an interval of about a day give a perfectly spherical figure in the stereoscope. When the principal spots are near either limb, two views taken at an interval of two days will combine, and even slight changes in the form of the spots do not prevent the perfect coalition of the two pictures.

Having already most fully described the methods pursued and the precautions to be taken to ensure good results in the case of photoselenography, it will be unnecessary for me here to enter into any details of the chemical part of the processes of photoheliography, for the methods are nearly the same in both cases. So far from seeking a surface less sensitive than ordinary collodion, it has been found advisable to use both the bath and collodion in a very sensitive condition, though it is not of course necessary to strain this sensitiveness to the utmost extent for solar photography, as in the case of lunar photography. The bath must, however, be always brought back to its best working state by means of oxide of silver, and subsequent addition of dilute nitric acid in case it has become acid by use. The collodion moreover is used in that condition which photographers would call very sensitive.